(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
31 January 2002 (31.01.2002)

PCT

(10) International Publication Number
WO 02/09198 A1

(51) International Patent Classification[7]: H01L 31/06, 31/078

(21) International Application Number: PCT/US01/41421

(22) International Filing Date: 26 July 2001 (26.07.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
09/625,970 26 July 2000 (26.07.2000) US

(71) Applicant *(for all designated States except US)*: **UNAXIS USA INC.** [US/US]; 10050 16th Street North, St. Petersburg, FL 33716 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **LEE, Jewon** [KP/KP]; Department of Optical Eng., Inje University, 607 O-bang-dong, Kimhae, Kyoung-nam 621-749 (KP). **DEVRE, Mike** [US/US]; 3130 Hillside Lane, Safety Harbor, FL 34695 (US). **JOHNSON, Dave** [GB/US]; 920 Belted Kingfisher Drive, Palm Harbor, FL 34683 (US). **MACKENZIE, Kenneth** [GB/US]; 1826 Eagle Ridge Boulevard, Palm Harbor, FL 34685 (US). **SASSERATH, Jay** [US/US]; 1922 Illinois Avenue NE, St. Petersburg, FL 33703 (US).

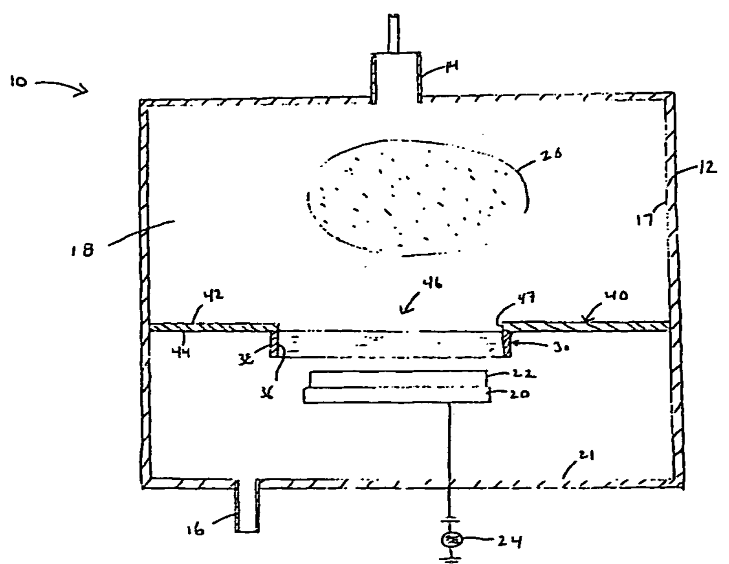
(74) Agents: **KAMINSKI, Michael, D.** et al.; Foley & Lardner, Washington Harbour, 3000 K Street, N.W., Suite 500, Washington, DC 20007-5109 (US).

(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

[Continued on next page]

(54) Title: ETCHING APPARATUS HAVING A CONFINEMENT AND GUIDE OBJECT FOR GAS FLOW OF PLASMA AND METHOD FOR USING SAME



(57) **Abstract:** A method and apparatus for anisotropically plasma etching semiconductor materials is disclosed. The apparatus includes an etching chamber for plasma etching which includes therein a gas confinement apparatus and/or a gas flow modifier to focus the plasma gas onto the substrate to be etched and provide uniform etch rates, modulation of sidewall profile shapes or surface morphology during processing. The gas confinement apparatus and the gas flow modifier are formed of any suitable shape and may include openings therein to produce a balanced gas flow rate. The apparatus is especially useful for etching GaAs and InP substrates.

WO 02/09198 A1

Published:
— *with international search report*
— *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments*

Etching Apparatus having a Confinement and Guide Object for Gas Flow of Plasma and Method for Using Same

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION

The invention relates to a method and apparatus for anisotropically plasma etching semiconductor materials whereby the gas flow to the substrate is improved.

2. DESCRIPTION OF THE FIELD

As the density of semiconductor devices increases, plasma etch processes are increasingly utilized because such processes can be employed to etch films in situ and avoid wet etch techniques. A typical plasma etch system includes a plasma processing chamber and a workpiece holder to support the workpiece in the chamber. Inlet ports introduce a reactant gas or gases into the chamber where electrodes are used to excite the gases into a plasma state in the chamber. One or more of the electrodes may be excited by a direct current (DC) voltage source or a radio frequency (RF) voltage source, often at frequencies ranging between about 2 MHz and about 13.56 MHz to couple energy from the power supply into the plasma. Typical methods for transferring the power into the gas include direct coupling, capacitive coupling, and inductive coupling. Often, coupling includes a combination of these methods. In addition, inductors (or coil arrangements) can be used in a chamber arrangement to inductively couple power into the process chamber to excite gases introduced in the chamber into a plasma state.

Plasma etch processes can be used to etch metals, semiconductors, inorganic insulators and organic films using reactive gases. Typical reactive gases include fluorine-containing gases, such as NF_3, SF_6, CHF_3, CF_4 or C_2F_6, sometimes in combination with O_2, Ar, N_2, or He. These gases are useful in obtaining desired etch rates, selectivities and uniformities, all of which must be precisely controlled. A mixture of chlorine and other halogen gases is the most popular gas chemistry for etching of dielectrics, metals and compound semiconductors such as, GaAs and InP. There has been a limitation to utilize the gas flow with current hardware configuration in plasma process equipment. The limitation is that significant volume of the gases inserted into a process chamber may be pumped away without reacting with a sample due to inadequate confinement of the gas flow onto the sample.

In order to obtain a substantially uniform etch across the substrate surface, it is necessary to create and maintain a uniform plasma over the substrate and to monitor changes in the plasma. For example, in an anisotropic etching technique, it is necessary to achieve a laterally exact defined recess (trench via contact) in the substrate. These deeply-extending recesses must have parallel sidewalls.

The individual structures to be etched into the substrate are usually defined by applying an etching mask(s) to the substrate by way of so-called masking layers, such as, for example, a photoresist layer, which after exposure to UV light and subsequent

developing, remains on the substrate, thereby protecting the underlying layer from the etchant.

A typical process for etching a contact via is described in Arleo et al, U.S. Pat. No. 5,176,790, which discusses etching a dielectric in a plasma using a mixture of fluorine-containing gases and nitrogen-containing gases. Dry etching of metals, such as aluminum and tungsten, can be performed either by reactive ion etching (RIE) or by plasma etching in the presence of a halide gas, such as chlorine or bromine-containing gases for aluminum etching and fluorine-containing gases for tungsten etching. In addition, dry etching of a laminated film having a metal silicide layer and a polycrystalline silicon layer can be performed using a mixed gas of SF_6 and O_2. Other gas combinations such as HBr, Cl_2 and O_2; NF_3, Cl_2 and O_2; Cl_2 and O_2; as well as other gases can also be used to perform dry etching processes.

In U.S. Patent No. 5,501,893, an etching process is disclosed wherein a silicon substrate first undergoes a plasma etching step which is followed by a second polymerizing step wherein exposed areas are covered by a polymer layer which forms a temporary etching stop. These two steps make up the process by alternately repeating the etching step and the polymerizing step.

A great amount of effort has been paid to attempt to improve uniformity across the wafer during plasma deposition and etching. It is understood to those of ordinary skill in this art that there are different mechanisms for each plasma process. For example, there

are two popular plasma etching processes for III-V semiconductors, such as GaAs. The first is non-selective etching and the other is selective etching. Gases for GaAs non-selective etching are typically based on Cl_2, BCl_3 and $SiCl_4$. Selective etching process, on the other hand, requires the addition of a fluorine-based gas, such as, SF_6 or CF_4 together with the chlorine gases. The radial distribution of etch rates for these two processes are the same. In both etching processes, the highest etch rate is usually found at the edge of the wafer while the lowest etch rate is usually found at the center of the wafer. The etch mechanism of the processes is generally understood to be reactant limited, which means that distribution of neutral gas reactants can play a key role for etch rate uniformity.

GB 2,327,909 relates to anisotropically plasma etching a silicon wafer in a plasma etching apparatus where the apparatus includes an aperture formed above the wafer. The aperture is formed from a perforated diaphragm. A vertical cylindrical aluminum screen is formed over the diaphragm.

U.S. Patent No. 5,891,348 discloses an apparatus for processing substrates which includes a process chamber having a gas distributor, a support for supporting a substrate in the process chamber, a plasma generator, and a focus ring. The focus ring has a wall surrounding the substrate to contain the plasma on the substrate surface. The focus ring also includes a channel, adjacent to, and extending continuously around the peripheral edge of the substrate surface. The inlet of the channel has a allows a sufficient amount of

process gas to flow into the channel in order to maintain substantially equal processing rates at the center and peripheral edge of the substrate surface.

In U.S. Patent No. 5,474,649, a focus ring for surrounding a workpiece/surface substrate during plasma processing is disclosed which includes a hollow annular assembly comprised of electrically insulating material and having a texturized surface. According to the patent,. the texturized ring is preferably a cylindrical structure which is texturized by surface abrasion, such as, bead blasting or chemical etching.

Rose et al., U.S. Patent No. 4,792,378 discloses a chemical vapor transport reactor gas dispersion disk for counteracting vapor pressure gradients. According to the patent, the gas dispersion disk provides a uniform deposition of material films on a semiconductor slice. The gas dispersion disk has a number of apertures arranged to increase the aperture area per unit of disk area when extending from the center of the disk to its outer peripheral edge. The apparatus also includes an apertured annular ring for providing an outlet of the gas vapors from the reactor chamber. Rose, U.S. Patent No. 4,820,371, discloses an apertured ring discussed in 4,792,378. The annular ring is used in a plasma reaction chamber and includes a central opening aperture for laterally retaining a semiconductor slice in the chamber. The ring also includes a plurality of gas exhaust ports for providing a back pressure within the chamber and for removing gases from the chamber.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to overcome the drawbacks of the prior art and to provide an apparatus that can be used to effectively confine and guide gas flows in the etching chamber to provide improved uniformity in a selective etching processes without degrading the uniformity in a non-selective etching. The apparatus according to the present invention can be used to confine and guide halogen gases such as, for example, SF_6, Cl_2, BCl_3 NF_3, CHF_3, CF_4, C_2F_6 and HBr, and their mixtures in plasma processing of semiconductor materials such as, for example, silicon, GaAs, InP, AlGaAs, InGaP, AlInGaP, AlN, AlGaN, GaN, metals or dielectrics, to improve etch rates and uniformity, and modulation of sidewall profile shapes or surface morphology during processing. By using the apparatus according to the present invention, the present inventors have discovered that it is possible to achieve over 5 μm/min of GaAs etch rate, an improvement of more than 30 % of the rate obtained without using the apparatus of the present invention under similar process conditions and in a similar chamber.

According to one embodiment of the invention, an etching apparatus for etching a substrate surface is provided wherein the etching apparatus includes a gas confinement apparatus located inside the etching chamber to focus the etching gas uniformly over the substrate. The method encompasses anisotropic plasma reactive ion etching wherein a desired plasma gas is input into the etching chamber, passed through the gas confinement apparatus located inside the etching chamber and focused so that the etching gas uniformly contacts the substrate.

According to another embodiment of the invention, an etching apparatus for etching a substrate surface is provided wherein the etching apparatus includes a gas flow modifier located inside the etching chamber to focus the etching gas uniformly over the substrate. The method encompasses anisotropic plasma reactive ion etching wherein a desired plasma gas is input into the etching chamber, passed through the gas flow modifier located inside the etching chamber and focused so that the etching gas uniformly contacts the substrate.

According to yet another embodiment of the invention, an etching apparatus for etching a substrate surface is provided wherein the etching apparatus includes both a gas confinement apparatus and a gas flow modifier located inside the etching chamber to focus the etching gas uniformly over the substrate. The method encompasses anisotropic plasma reactive ion etching wherein a desired plasma gas is input into the etching chamber, passed through the gas confinement apparatus and the gas flow modifier inside the etching chamber and focused so that the etching gas uniformly contacts the substrate.

Other objects, features and advantages of the invention will become apparent from the following detailed description of the preferred embodiments of the invention.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 illustrates an exemplary cross-sectional view of an etching apparatus according to the present invention.

Figure 2 illustrates a perspective cross-sectional view of a gas confinement apparatus according to the present invention.

Figure 3 illustrates a perspective cross-sectional view of another gas confinement apparatus according to the present invention.

Figure 4 is a graph showing the effect of the presence of a gas confinement apparatus in the etching chamber on the etch rate of the substrate.

Figure 5 is a scanning electron microscopy photo of a GaAs substrate etched according to the present invention.

Figures 6A and 6B illustrate a gas flow modifier according to the present invention.

Figures 7A and 7B illustrate a second gas flow modifier according to the present invention.

Figures 8A and 8B illustrate a third gas flow modifier according to the present invention.

Figure 9 is a graph showing the radial distribution of etch depth with and without a gas flow modifier.

Figure 10 illustrates a gas flow optimizer according to the present invention.

Figure 11 illustrates a second gas flow optimizer according to the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following detailed description, the preferred embodiments are described in sufficient detail to enable those skilled in the art to practice the invention, and it is to be understood that other embodiments may be utilized, and that changes may be made without departing from the spirit and scope of the present invention.

As set forth above, there are different requirements for each plasma process. For example, to etch III-V semiconductors, such as GaAs, there are two popular plasma etching techniques. The first is non-selective etching and the other is selective etching. Gases for GaAs non-selective etching are typically based on Cl_2, BCl_3 and $SiCl_4$ while a selective etching process, on the other hand, requires the addition of a fluorine-based gas, such as, SF_6 or CF_4 together with other chlorine gases. The radial distribution of etch rates for these two processes will likely be the same. In both etching processes, the highest etch rate is usually found at the edge of the water and the lowest etch rate is usually found at the center of the wafer. The etch mechanism of both processes typically is reactant-limited, which means that distribution of neutral gas reactants can play a key role for etch rate uniformity in selective etching of GaAs. The present invention provides improved uniformity in both etching processes, i.e. selective and non-selective etching.

Reference is made to Fig. 1. This figure shows a cross sectional view of a exemplary processing apparatus 10 of the present invention for plasma etching a substrate 22. The apparatus 10 includes an enclosed etching chamber 18 having an exterior peripheral wall 12. Plasma process gas which is used to etch the substrate 22 is introduced

into the etching chamber 18 through an inlet 14. The plasma process gas 26 may be introduced into the etching chamber 18 directly, by a "shower head" gas diffuser (not shown) or by any method known in the art. The plasma gas 26 can be formed by inductive coupling by using a coil (not shown) wrapped around the chamber 18, by capacitive coupling using process electrodes (not shown) in the chamber 18, or by a combination thereof. The plasma gas 26 may include fluorine-containing gases, such as NF_3, SF_6, CHF_3, CF_4 or C_2F_6, sometimes in combination with O_2, Ar, N_2, or He, or Cl_2, BCl_3 and $SiCl_4$, or SF_6 or CF_4 together with the chlorine gases. Preferably, the plasma gas is Cl_2, BCl_3 and $SiCl_4$ for non-selective etching of the substrate 22 and SF_6 or CF_4 together with Cl_2, BCl_3 and $SiCl_4$ for selective etching of the substrate 22. An outlet 16 is provided for removing the plasma process gas 26 from the chamber 18.

The gas mixtures have a flow rate of from about 0 to 1000 sccm, and preferably from about 50 - 300 sccm. The pressure of the process is from about 1 and 200 mT, and preferably from 10 to 100 mT at an output preferably between 0 and 5000W, a microwave, ICP, TCP, helicon, ECR or other high density excitation source. The plasma gas 26 is input at a gas flow of between 0 and 1000 sccm and a processing pressure between 5 and 100 mT. The plasma generation for etching preferably takes place with an RF excitation or other high density source at outputs between 0 and 5000W (up to about 2.45 GHz). A RF (radio frequency) bias for ion acceleration may be applied to the substrate electrode. The substrate bias is preferably between 0 and 500V, and can be achieved with a high-frequency supply (13.56 MHz) at outputs between 0 and 500W. The etching may be performed for a

time period in order to yield an etch depth of about 0.1 μm to about 500 μm. The absolute depth of the etching is dependent upon the thickness of the substrate to be etched and the amount of etching desired.

The substrate 22 is placed within etching chamber 18 on substrate support 20. The substrate support 20 can be grounded or biased by connection to supply 24. The substrate 22 can be any semiconductor materials such as, for example, silicon, SOI, GaAs, InP, AlGaAs, InGaP, AlInGaP, AlN, AlGaN, GaN, metals or dielectrics. Preferably, the substrate is GaAs or InP.

A gas confinement apparatus 40 surrounding substrate 22 is placed in the etching chamber 18. The gas confinement apparatus 40 can be designed as a structure attached to the interior surface 17 of wall 12 as shown in Fig. 1, or as an integral portion of the substrate support 20 (not shown).

The gas confinement apparatus 40 has an upper surface 42 and a lower surface 44 and further includes an opening 46 formed in the center for containing and directing the flow of process gas or plasma 26 on the substrate 22. The wall 47 guides the flow of fresh reactive process gas 26 from the inlet 14 to the substrate 22. The gas confinement apparatus is discussed in more detail below with reference to Figs. 2 and 3.

The apparatus 10 may also contain a gas flow modifier 30. The gas flow modifier 30 may be incorporated into the apparatus 10 with or without gas confinement apparatus 40. For simplicity, these two elements are shown together inside etching chamber 18;

however, it should be understood that either may be used alone or in combination with the other. The gas flow modifier 30 can be designed as a free-standing ring structure resting on the substrate support 20 (not shown), as an integral portion of the gas confinement apparatus 40 as shown in Fig. 1, or as a fixed ring structure attached to the sidewall 17 or interior bottom surface 21 of etching chamber 18. The gas flow modifier 30 has an outside wall 38 and an inside wall 36. When the gas flow modifier is integrally attached to the gas confinement apparatus 40, as illustrated in Fig. 1, the opening of the gas flow modifier is preferably the same as the opening 46 in the gas confinement apparatus 40.

During processing of substrates in the etching chamber 18, the plasma gas 26 is focused onto the substrate 22 by either one of, or both, the gas confinement apparatus 40 and/or the gas flow modifier 30. These elements allow the plasma 26 to be uniformly distributed and focused onto the substrate 22.

Reference is now made to Figs. 2 and 3. Figure 2 shows a perspective cross-sectional view of a gas confinement apparatus 40 according to the present invention. The gas confinement apparatus 40 can be formed in any suitable shape. Accordingly, the gas confinement apparatus 40 may be circular, square, rectangular or the like. The opening 46 can be of any suitable size to allow the plasma gases, neutrals and ions, 26 which are generated by a plasma source to flow through the opening 46 in the gas confinement apparatus 40 and arrive on the substrate 22. Preferably, the opening 46 is sized to surround the substrate 22. The opening 46 may also be of any suitable shape, such as, for example, circular, square, rectangular, triangular or the like. It should be understood that the

opening is separate and distinct from the shape of the gas confinement apparatus 40. Thus, for example, for substrates having a diameter of 203.2 mm (8-inch), a suitable inner diameter of the opening 46 is from about 200 mm to about 300 mm, and more preferably from about 225 to about 275 mm. The thickness of the wall 47 is sufficiently thick to focus the flow of the plasma gas 26 to the substrate 22. Thus, the thickness of the wall 47 depends upon the process conditions in the process chamber 18. A suitable thickness for a 150 to 300 mm (6 to 12 inch) diameter substrate is from about 1 to about 5 mm, preferably about 2 to about 3 mm.

Reference is now made to Fig. 3. This figure shows another embodiment of the gas confinement apparatus 41 according to the present invention. The gas confinement apparatus 41 may also be formed in any suitable shape. Accordingly, the gas confinement apparatus 41 may be circular, square, rectangular or the like. The opening 46 can be of any suitable size and shape to allow the plasma gases, neutrals and ions, 26 which are generated by a plasma source to flow through the opening 46 in the gas confinement apparatus 41 and arrive on the substrate 22. Preferably, the opening 46 is sized to surround the substrate 22. Thus, for example, the opening may be from about 200 mm to about 300 mm, and preferably from about 225 to about 275 mm. The thickness of the wall 47 is sufficiently thick to focus the flow of the plasma gas 26 to the substrate 22. A suitable thickness is from about 1 to about 5 mm, preferably from about 2 to about 3 mm. The gas confinement apparatus 41 further includes openings 43 in the apparatus. The diameter of the openings 43 maybe from about 5 mm to about 30 mm, and preferably from about 10 to

15 mm. The number of the opening 43 can be about 5 to 30, and preferably about 10-15. The openings 43 include inside walls 45 which pass completely through the thickness of the gas confinement apparatus 41. While the openings 43 are depicted as being round, the openings 43 may be present in any shape, size and density such that the gas confinement apparatus 41 allows a balanced flow of the plasma gas 26 onto wafer 22. Furthermore, openings 43 should be formed so that the flow of plasma gas 26 onto wafer 22 is uniform and provides a high process rate. For example, the openings 43 may be formed such that their density is greater nearer the outer perimeter of the gas confinement apparatus 41. Likewise, the openings 43 may be formed such that their density is greater nearer the inner perimeter of the gas confinement apparatus 41. Additionally, the openings 43 may be formed such that there are circular shaped openings 43 near the outer perimeter of the gas confinement apparatus 41 while square shaped openings 43 are formed near the inner portion of the gas confinement apparatus 41.

Reference is now made to Fig. 4. This figure shows the gas etch rate of a GaAs substrate in an etching chamber under identical conditions except in the first instance there was no gas confinement apparatus present in the chamber while in the second instance a gas confinement apparatus was placed therein. As can be seen from the figure, the etch rate of the substrate without the gas confinement apparatus was about 3.5 microns/minute while when the gas confinement apparatus was present in the etching chamber, the GaAs substrate was etched at a rate of about 5 microns/minute. The process condition was low ICP power, low RIE power. The process chemistry was chlorine-based. GaAs etch rate was 3.5

μm/min. However, it is noted that GaAs etch rate of 5 μm/min could be achieved with a confinement object at the fixed process condition. This indicates that the confinement object effectively transfers the neutral gas flow onto the GaAs wafer and provides an enhanced etch rate. Accordingly to etch mechanism, the limiting factor of GaAs etch rate is believed to be related to the number of gas reactants present on the GaAs subtrate. The confinement object controlled and guided the path of gas flux on the GaAs and it significantly improved the etch rate of the GaAs substrate.

Additionally, Fig. 5 shows a scanning electron microscopy photo of GaAs via etched with a gas confinement apparatus present in the etching chamber. As can be seen from the figure, the gas confinement apparatus provides a GaAs etch via which has uniform depth and smooth, vertical sidewalls. Another role of gas confinement object is to make ions more directional to the substrate. For plasma etching, anisotropic etching is one advantage over wet etching. Anisotropic etching is important for device processing since CD (critical dimension) loss must be optimized. For GaAs via etching, it is common to see some undercutting of the sidewall after plasma etching due to insufficient sidewall passivation. The results are more evident with deep feature etching (>6μm.) as it will make subsequent metal contact on the via hole difficult. However, with a gas confinement object, it is noticed that a vertical sidewall is achieved without undecutting the sidewall, even after 70 μm etching of a 40 μm diameter via. The results prove that the gas confinement object helps control gas flux and the direction of ions to achieve the desired sidewall shape after etching.

Reference is now made to Figs. 6A and 6B. Figure 6A shows a perspective cross-sectional view of a gas flow modifier 30 according to the present invention. As set forth above, the gas flow modifier 30 may be incorporated into the apparatus 10 with or without gas confinement apparatus 40. The gas flow modifier 30 can be designed as a free-standing ring structure resting on the substrate support 20 (not shown), as an integral portion of the gas confinement apparatus 40 as shown in Fig. 1, or as a fixed ring structure attached to the sidewall 17 and/or the interior bottom surface 21 of etching chamber 18. The gas flow modifier is positioned near the substrate 22 in order to improve the uniformity in selective etching processes without degrading the uniformity in non-selective etching. The gas flow modifier 30 has an outside wall 38 and an inside wall 36. When the gas flow modifier is integrally attached to the gas confinement apparatus 40, as illustrated in Fig. 1, the opening of the gas flow modifier is preferably the same as the opening 46 in the gas confinement apparatus 40. The gas flow modifier 30 may be formed of a dielectric material, such as quartz, a ceramic, such as aluminum oxide or a conductor, such as a metal (for example aluminum). If the gas flow modifier 30 is formed of a metal, then the gas flow modifier 30 can be grounded or biased in order to control ion direction in the plasma.

The gas flow modifier 30 can be formed in any suitable shape. For example, the gas flow modifier 30 can be circular, square, rectangular or the like. The opening formed in the gas flow modifier 30 can be of any suitable size to allow the plasma gases, neutrals and ions, 26 which are generated by a plasma source to flow through the opening to the substrate 22. Thus, for example, for substrates having a diameter of 203.2 mm (8-inch), a

suitable inner diameter of the opening of the gas flow modifier 30 is from about 200 mm to about 250 mm, and more preferably from about 205 to 225 mm. The thickness of the wall of the gas flow modifier 30 is sufficiently thick to focus the flow of the plasma gas 26 to the substrate 22 while maintaining structural stability of the device. Thus, the thickness of the gas flow modifier 30 depends upon the process conditions in the process chamber 18 as well as the location of the gas flow modifier in the chamber 18. A suitable thickness for a 150 to 300 mm (6 to 12 inch) diameter substrate is from about 2 to about 10 mm, preferably about 3 to about 5 mm.

The gas flow modifier 30 has a height h which is sufficient to reduce the flow or diffusive transport of stagnant reactive process gas species circulating in the process chamber 18 to the substrate 22. The height h of the gas flow modifier 30 depends upon the process conditions in the process chamber 18. Thus, for example, a suitable height h for a 150 to 300 mm (6 to 12 inch) diameter substrate processed using the process conditions described herein is from about 10 to about 50 mm, preferably 15 to 25 mm, most preferably about 20 mm.

Reference is now made to Fig. 6B. This figure shows a gas flow modifier 31 according to the present invention. The gas flow modifier 31 can also be formed in any suitable shape and may be formed of the materials described above. For example, the gas flow modifier 31 can be circular, square, rectangular or the like and may be formed of a dielectric or a ceramic. A suitable inner diameter of the opening of the gas flow modifier 31 is from about 200 mm to about 250 mm, and more preferably from about 205 to 225

mm. The thickness of the wall of the gas flow modifier 31 is sufficiently thick to focus the flow of the plasma gas 26 to the substrate 22 while maintaining structural stability of the device. Thus, the thickness of the gas flow modifier 31 depends upon the process conditions in the process chamber 18. A suitable thickness for a 150 to 300 mm (6 to 12 inch) diameter substrate is from about 2 to about 10 mm, preferably about 3 to about 7 mm. Furthermore, the gas flow modifier 31 has a height h which is sufficient to reduce the flow or diffusive transport of stagnant reactive process gas species circulating in the process chamber 18 to the substrate 22. The height h of the gas flow modifier 31 depends upon the process conditions in the process chamber 18. Thus, for example, a suitable height h for a 150 to 300 mm (6 to 12 inch) diameter substrate processed using the process conditions described herein is from about 10 to about 50 mm, preferably 15 to 25 mm, most preferably about 20 mm.

The gas flow modifier 31 further includes openings 37 in the wall of the gas flow modifier 31. The openings 37 pass completely through the thickness of the gas flow modifier 31. While the openings 37 are depicted as being circular, it should be understood that the openings 37 may be present in any shape, size and density such that the gas flow modifier 31 allows a balanced flow of the plasma gas 26 onto wafer 22. Furthermore, openings 37 should be formed so that the flow of plasma gas 26 onto wafer 22 is uniform and provides a high process rate. For example, the openings 43 may be formed such that their density is upper portion of the gas flow modifier 31. Likewise, the openings 37 may be formed such that their density is greater nearer the middle of the gas flow modifier 31.

Reference is now made to Figs. 7-8. Figure 7A illustrates a gas flow modifier 32 where the inner surface of the gas flow modifier forms an angle α with a vertical axis that is perpendicular to the plane of the substrate 22, to form an inverted tapered conical surface that smoothly directs the flow of plasma gas 26 to the substrate 22. Preferably, the angle α is an acute angle. More preferably, the angle α is from about 10° to about 75°, more preferably from about 15° to about 45°, and most preferably about 30°. Figure 7B illustrates a gas flow modifier 33 where the inner surface of the gas flow modifier forms an angle α with a vertical axis that is perpendicular to the plane of the substrate 22, to form an inverted tapered conical surface that smoothly directs the flow of plasma gas 26 to the substrate 22 in a converging pattern. The gas flow modifier 33 additionally includes openings 37 in the wall of the gas flow modifier 33 which pass completely through the wall of the gas flow modifier 33. Again, while the openings 37 are depicted as being circular, it should be understood that the openings 37 may be present in any shape, size and density such that the gas flow modifier 33 allows a balanced flow of the plasma gas 26 onto wafer 22. Furthermore, openings 37 should be formed so that the flow of plasma gas 26 onto wafer 22 is uniform and provides a high process rate.

Figure 8A illustrates a gas flow modifier 34 where the inner surface of the gas flow modifier forms an angle β with a vertical axis that is perpendicular to the plane of the substrate 22, to form a tapered conical surface that smoothly directs the flow of plasma gas 26 to the substrate 22 in a diverging pattern. Preferably, the angle β is an acute angle. More preferably, the angle β is from about 10° to about 75°, more preferably from about

15° to about 45°, and most preferably about 30°. Figure 8B illustrates a gas flow modifier 35 where the inner surface of the gas flow modifier forms an angle β with a vertical axis that is perpendicular to the plane of the substrate 22, to form a tapered conical surface that smoothly directs the flow of plasma gas 26 to the substrate 22 in a diverging pattern. The gas flow modifier 35 additionally includes openings 37 in the wall of the gas flow modifier 35 which pass completely through the wall of the gas flow modifier 35. While the openings 37 are depicted as being circular, it should be understood that the openings 37 may be present in any shape, size and density such that the gas flow modifier 35 allows a balanced flow of the plasma gas 26 onto wafer 22.

Reference is now made to Fig. 9. This figure shows the radial distribution of etch depth with and without a gas flow modifier. As can be seen from the figure, when a GaAs substrate is etched with a BCl_3/SF_6, 300W ICP source power, 15 WRIE chuck power, 5 mTorr chamber pressure without a gas flow modifier, the etching rate at the wafer edge is greater that the etching rate closer to the center of the substrate. In contrast, when a gas flow modifier is added to the etching chamber, a more uniform etching across the wafer. Thus, the presence of the gas flow modifier provides a uniform etch rate across the entire wafer

Reference is now made to Figs. 10 and 11. Fig. 10 shows a gas flow optimizer 50 formed from a gas confinement apparatus 40 together with a gas flow modifier 31. The gas confinement apparatus 40 is similar to those discussed above with reference to Fig. 2; however, as discussed above, the gas confinement apparatus 40 is square shaped. The gas

flow modifier 31 is attached as an integral portion of the gas confinement apparatus 40. The gas flow modifier 31 is integrated into the gas confinement apparatus 40 such that the gas flow modifier 31 is located adjacent to and below the gas confinement apparatus 40 to form the gas flow optimizer 50. As discussed above, the opening in the gas flow modifier 31 is preferably the same as the opening 46 in the gas confinement apparatus 40. Additionally, the gas flow modifier 31 and the gas flow confinement apparatus 40 have a thickness, height and positioning within the chamber to improve the etch rate, uniformity, and modulation of sidewall profile shapes or surface morphology of the substrate. As illustrated in this figure, the gas flow modifier 31 includes openings 37 so that the flow of plasma gas 26 onto wafer 22 is uniform and provides a high process rate.

Figure 11 shows a gas flow optimizer 51 formed from a gas confinement apparatus 41 together with a gas flow modifier 30. The gas confinement apparatus 41 is similar to those discussed above with reference to Fig. 3; however, as discussed above, the gas confinement apparatus 41 is square shaped. The gas flow modifier 30 is also attached as an integral portion of the gas confinement apparatus 41. The gas flow modifier 30 is integrated into the gas confinement apparatus 41 such that the gas flow modifier 30 is located adjacent to and below the gas confinement apparatus 41 to form the gas flow optimizer 51. As discussed above, the opening in the gas flow modifier 30 is preferably the same as the opening 46 in the gas confinement apparatus 41. Additionally, the gas flow modifier 30 and the gas flow confinement apparatus 41 have a thickness, height and positioning within the chamber to improve the etch rate, uniformity, and modulation of

sidewall profile shapes or surface morphology of the substrate. As illustrated in this figure, the gas confinement apparatus 41 includes openings 43 so that the flow of plasma gas 26 onto wafer 22 is uniform and provides a high process rate. While these figures illustrate gas flow optimizers where either the gas confinement apparatus or gas flow modifier portion of the gas flow optimizer includes openings, it should be understood that the invention is not so limited. For example, either the gas confinement apparatus or gas flow modifier portion of the gas flow optimizer, or both may have openings. Likewise, there need not be any openings present in the gas flow optimizer. The person having ordinary skill in the art understands whether and where the openings should be placed to provide a uniform etch.

The apparatus and methods described herein are but some of many that could be used within the scope of the present invention. Accordingly, the above description is only illustrative of preferred embodiments which can achieve the features and advantages of the present invention. It is not intended that the invention be limited to the embodiments described in detail herein.

CLAIMS

What is claimed is:

1. A method of etching a substrate in a plasma etching chamber, comprising:

placing a substrate in the etching chamber;

introducing plasma gas in the plasma etching chamber, and maintaining the plasma gas at process conditions suitable for etching said substrate; and

focusing said plasma gas onto said substrate by first passing said plasma gas over a gas confinement member and subsequently passing said plasma gas over a gas flow modifier, wherein said gas confinement member has a central opening for said plasma gas to pass through and wherein said gas flow modifier has an outer wall and an inner wall wherein said inner wall defines a hollow aperture for said plasma gas to flow onto said substrate.

2. The method according to claim 1, wherein said substrate is selected from the group consisting of silicon, GaAs, InP, AlGaAs, InGaP, AlInGaP, AlN, AlGaN, and GaN.

3. The method according to claim 1, wherein said substrate is GaAs.

4. The method according to claim 1, wherein said substrate is InP.

5. The method according to claim 1, wherein said plasma etching gas includes Cl_2, BCl_3, $SiCl_4$ and mixtures thereof.

6. The method according to claim 1, wherein said plasma etching gas is selected from the group consisting of Cl_2, BCl_3 and $SiCl_4$ in combination with SF_6 or CF_4.

7. The method according to claim 1, wherein said gas confinement element further comprises openings in said element.

8. The method according to claim 7, wherein said openings have a circular cross-section.

9. The method according to claim 1, wherein said gas flow modifier further comprises openings in said walls.

10. The method according to claim 9, wherein said openings have a circular cross-section.

11. The method according to claim 1, wherein said gas flow modifier has a frusto-conical shape and said inner wall of said gas flow modifier is at an acute angle with respect to the normal to the plane of the surface of the substrate.

12. The method according to claim 11, wherein said acute angle is from about 15 to about 45 degrees.

13. The method according to claim 1, wherein said gas flow modifier has a inverted conical shape and said inner wall of said gas flow modifier is at an acute angle with respect to the normal to the plane of the surface of the substrate.

14. The method according to claim 13, wherein said acute angle is from about 15 to about 45 degrees.

15. A method of etching a GaAs substrate in a plasma etching chamber, comprising:

placing a GaAs substrate in the etching chamber;

introducing plasma gas in the plasma etching chamber, and maintaining the plasma gas at process conditions suitable for etching said GaAs substrate; and

focusing said plasma gas onto said GaAs substrate by first passing said plasma gas over a gas confinement member and subsequently passing said plasma gas over a gas flow modifier, wherein said gas confinement member has a central opening for said plasma gas to pass through and wherein said gas flow modifier has an outer wall and an inner wall wherein said inner wall defines a hollow aperture for

said plasma gas to further flow onto said GaAs substrate.

16. The method according to claim 15, wherein said plasma etching gas includes Cl_2, BCl_3, $SiCl_4$, and mixtures thereof.

17. The method according to claim 15, wherein said plasma etching gas includes Cl_2, BCl_3, $SiCl_4$, and mixtures thereof, in combination with SF_6 or CF_4.

18. The method according to claim 15, wherein said gas confinement element further comprises openings in said element.

19. The method according to claim 18, wherein said openings have a circular cross-section.

20. The method according to claim 15, wherein said gas flow modifier further comprises openings in said walls.

21. The method according to claim 20, wherein said openings have a circular cross-section.

22. The method according to claim 15, wherein said gas flow modifier has a frusto-conical shape and said inner wall of said gas flow modifier is at an acute angle with respect to the normal to the plane of the surface of the substrate.

23. The method according to claim 22, wherein said acute angle is from about 15 to about 45 degrees.

24. The method according to claim 15, wherein said gas flow modifier has a inverted conical shape and said inner wall of said gas flow modifier is at an acute angle with respect to the normal to the plane of the surface of the substrate.

25. The method according to claim 24, wherein said acute angle is from about 15 to about 45 degrees.

26. The method according to claim 22, wherein said wherein said gas flow modifier further comprises openings in said walls.

27. The method according to claim 24, wherein said wherein said gas flow modifier further comprises openings in said walls.

28. An apparatus for etching a substrate in a plasma etching chamber, comprising:

an etching chamber having a gas input for inputting plasma etching gas;

a plasma generator;

a support for supporting a substrate in said chamber;

a gas confinement member; and

a gas flow modifier, wherein said gas confinement member has a predetermined thickness and has a central opening for plasma to pass through and wherein said gas flow modifier has an outer wall and an inner wall wherein said inner wall defines a hollow aperture for plasma gas to flow through, and wherein said gas flow modifier is located above said support and said gas confinement element is located above said gas flow modifier and below said gas input.

29. The apparatus according to claim 28, wherein said gas confinement element further comprises openings in said element.

30. The apparatus according to claim 29, wherein said openings have a circular cross-section.

31. The apparatus according to claim 29, wherein said openings have a rectangular cross-section.

32. The apparatus according to claim 28, wherein said gas flow modifier further comprises openings in said walls.

33. The apparatus according to claim 32, wherein said openings have a circular cross-section.

34. The apparatus according to claim 32, wherein said openings have a rectangular cross-section.

35. The apparatus according to claim 28, wherein said gas flow modifier has a frusto-conical shape and said inner wall of said gas flow modifier is at an acute angle with respect to the normal to the plane of the surface of the substrate.

36. The apparatus according to claim 35, wherein said acute angle is from about 15 to about 45 degrees.

37. The apparatus according to claim 28, wherein said gas flow modifier has a inverted conical shape and said inner wall of said gas flow modifier is at an acute angle with respect to the normal to the plane of the surface of the substrate.

38. The apparatus according to claim 37, wherein said acute angle is from about 15 to about 45 degrees.

39. The apparatus according to claim 35, wherein said gas flow modifier further comprises openings in said walls.

40. The apparatus according to claim 39, wherein said openings have a circular cross-section.

41. The apparatus according to claim 39, wherein said openings have a rectangular cross-section.

42. The apparatus according to claim 37, wherein said gas flow modifier further comprises openings in said walls.

43. The apparatus according to claim 42, wherein said openings have a circular cross-section.

44. The apparatus according to claim 42, wherein said openings have a rectangular cross-section.

45. An apparatus for etching a substrate in a plasma etching chamber, comprising:

an etching chamber having a gas input for inputting plasma etching gas;

a plasma generator;

a support for supporting a substrate in said chamber; and

a gas flow modifier, wherein said gas flow modifier has an outer wall and an inner wall wherein said inner wall defines a hollow aperture for plasma gas to flow through and said gas flow modifier has an inverted conical shape and said inner wall of said gas flow modifier is at an acute angle with respect to the normal to the plane of the surface of the substrate.

46. The apparatus according to claim 45, wherein said acute angle is from about 15 to about 45 degrees.

47. The apparatus according to claim 45, wherein said gas flow modifier further comprises openings in said walls.

48. The apparatus according to claim 47, wherein said openings have a circular cross-section.

49. The apparatus according to claim 47, wherein said openings have a rectangular cross-section.

50. A gas confining apparatus comprising:

a gas confinement member; and

a gas flow modifier, wherein said gas confinement member has a predetermined thickness and has a central opening for plasma to pass through and wherein said gas flow modifier has an outer wall and an inner wall wherein said inner wall defines a hollow aperture for plasma gas to flow through, and wherein said gas confinement element is formed above said gas flow modifier.

51. The gas confining apparatus according to claim 50, wherein said gas confinement element further comprises openings in said element.

52. The gas confining apparatus according to claim 51, wherein said openings have a circular cross-section.

53. The gas confining apparatus according to claim 51, wherein said openings have a rectangular cross-section.

54. The gas confining apparatus according to claim 50, wherein said gas flow modifier further comprises openings in said walls.

55. The gas confining apparatus according to claim 54, wherein said openings have a circular cross-section.

56. The gas confining apparatus according to claim 54, wherein said openings have a rectangular cross-section.

57. The gas confining apparatus according to claim 50, wherein said gas flow modifier has a frusto-conical shape and said inner wall of said gas flow modifier is at an acute angle with respect to the normal to the plane of the surface of said gas confinement member.

58. The gas confining apparatus according to claim 57, wherein said acute angle is from about 15 to about 45 degrees.

59. The gas confining apparatus according to claim 50, wherein said gas flow modifier has a inverted conical shape and said inner wall of said gas flow modifier is at an acute angle with respect to the normal to the plane of the surface of said gas confinement member.

60. The gas confining apparatus according to claim 59, wherein said acute angle is from about 15 to about 45 degrees.

61. The gas confining apparatus according to claim 57, wherein said gas flow modifier further comprises openings in said walls.

62. The gas confining apparatus according to claim 61, wherein said openings have a circular cross-section.

63. The gas confining apparatus according to claim 61, wherein said openings have a rectangular cross-section.

64. The gas confining apparatus according to claim 59, wherein said gas flow modifier further comprises openings in said walls.

65. The gas confining apparatus according to claim 64, wherein said openings have a circular cross-section.

66. The gas confining apparatus according to claim 64, wherein said openings have a rectangular cross-section.

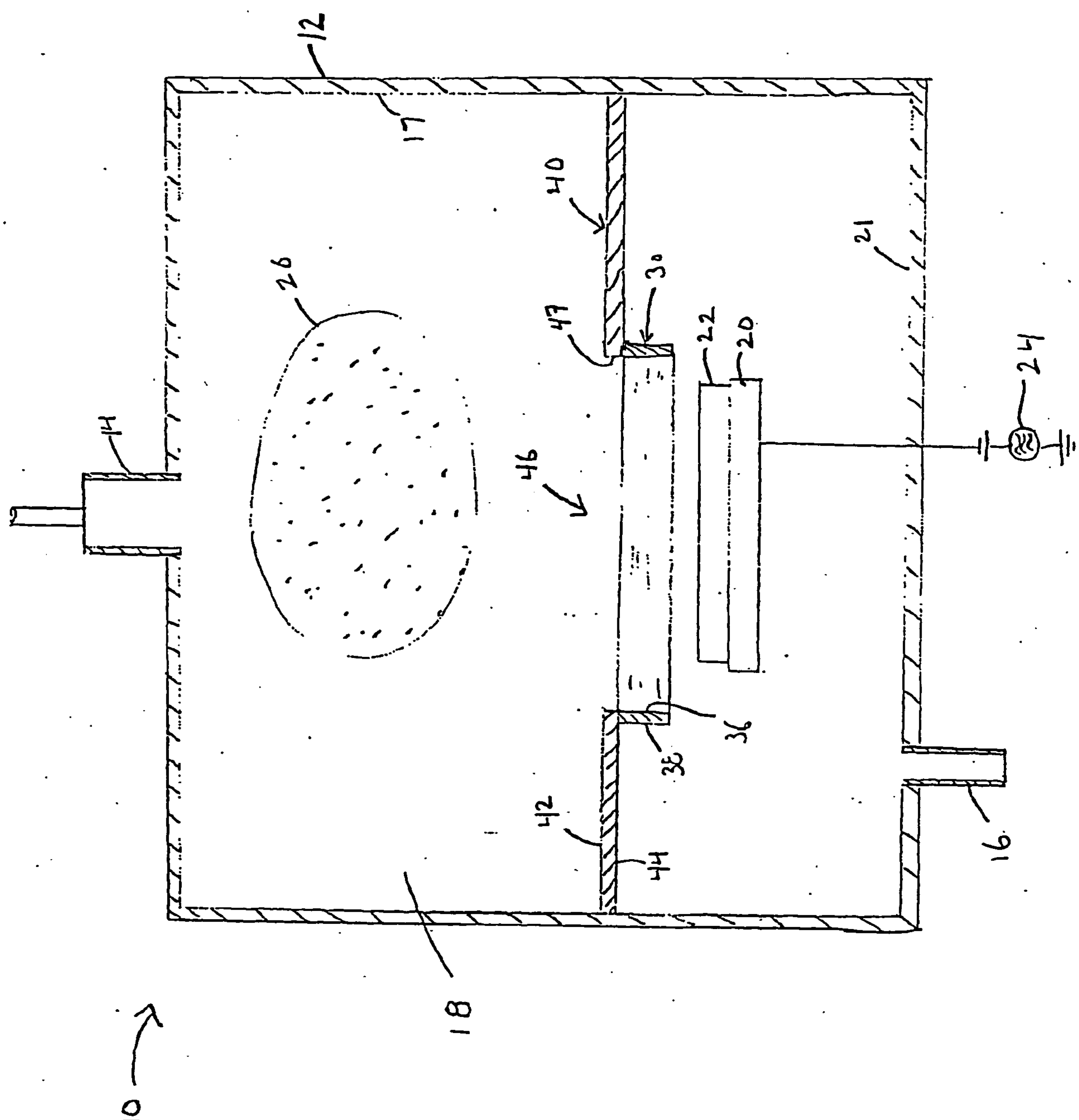


FIG. 1

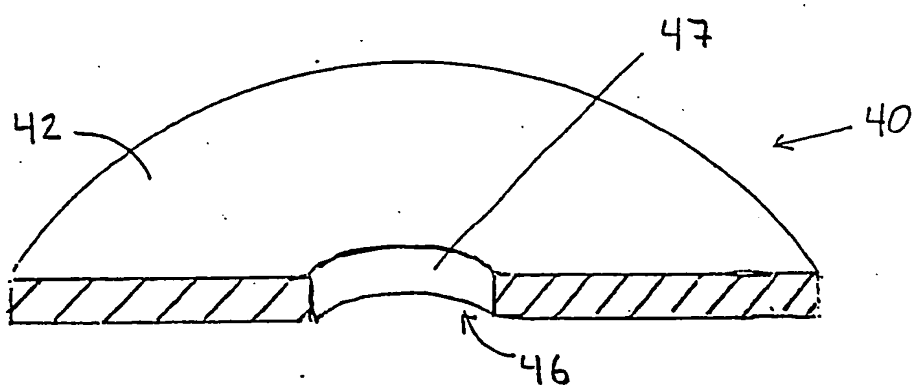


FIG 2

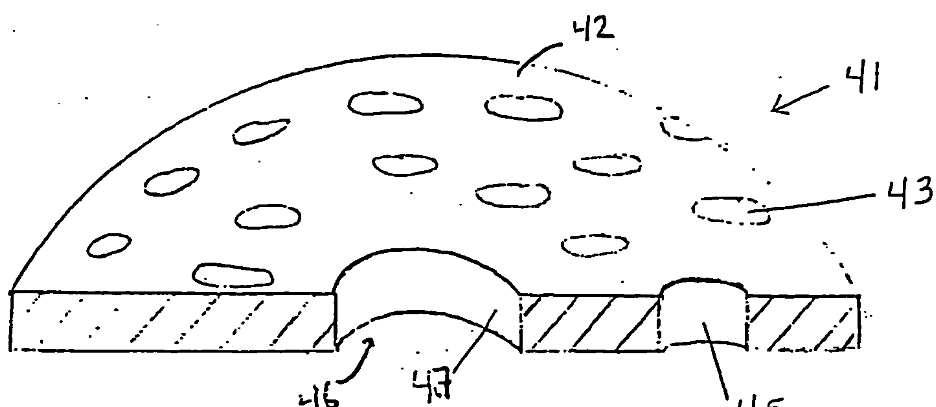


FIG 3

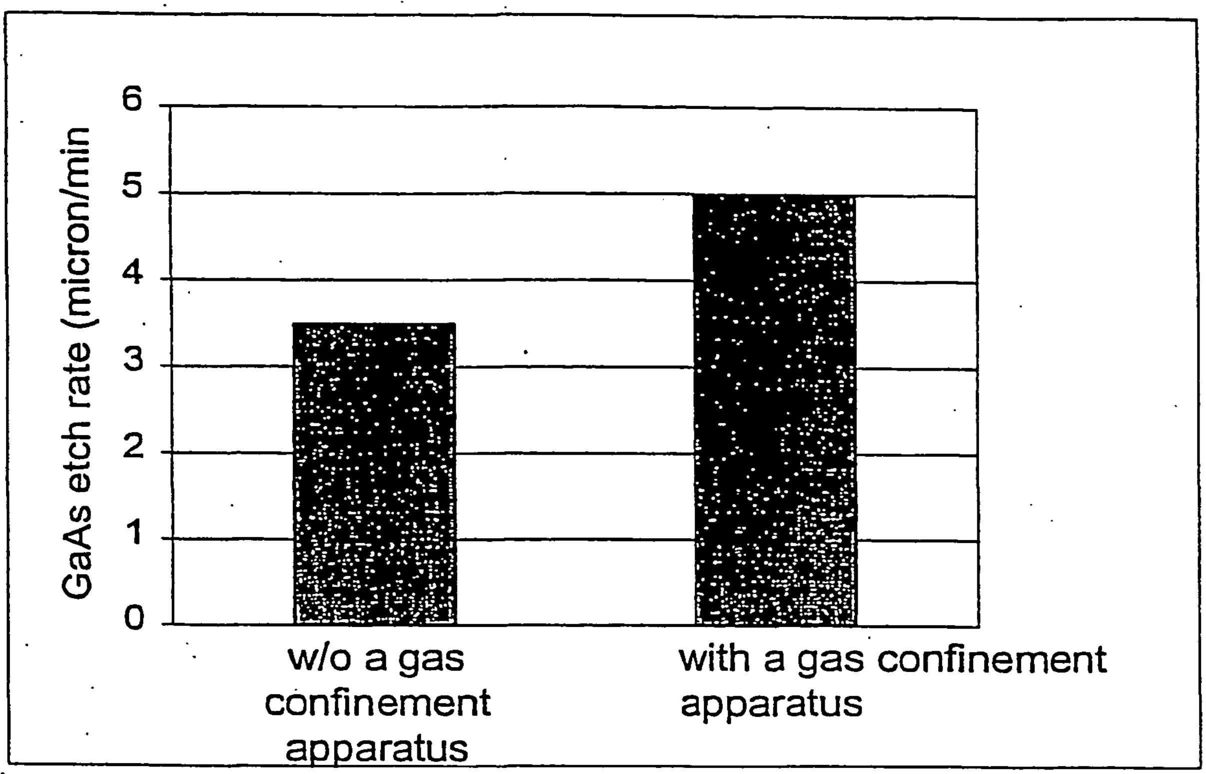
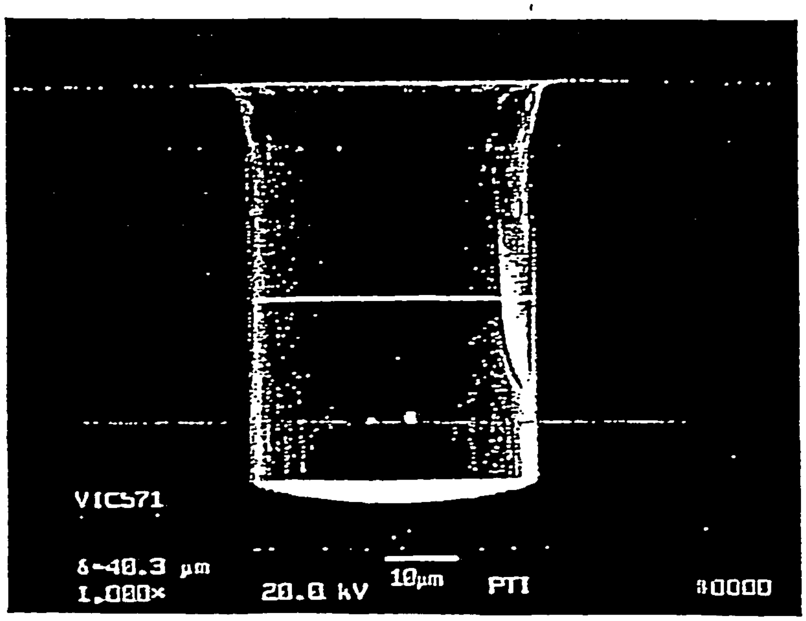


Figure 4 Etch rate of GaAs with and without a gas confinement apparatus.

Figure 5 Scanning electron microscopy photo after etching with a gas confinement apparatus .



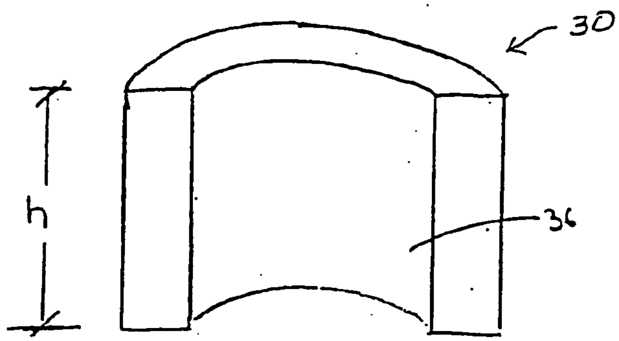


FIG. 6A

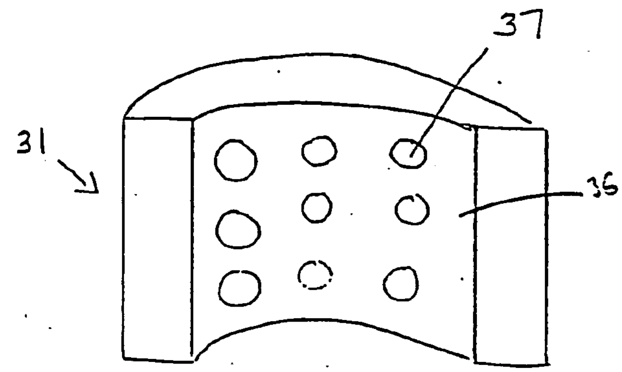


FIG. 6B

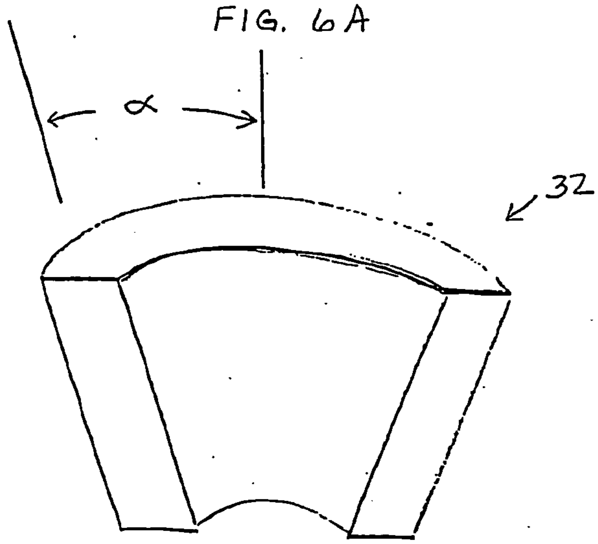


FIG. 7A

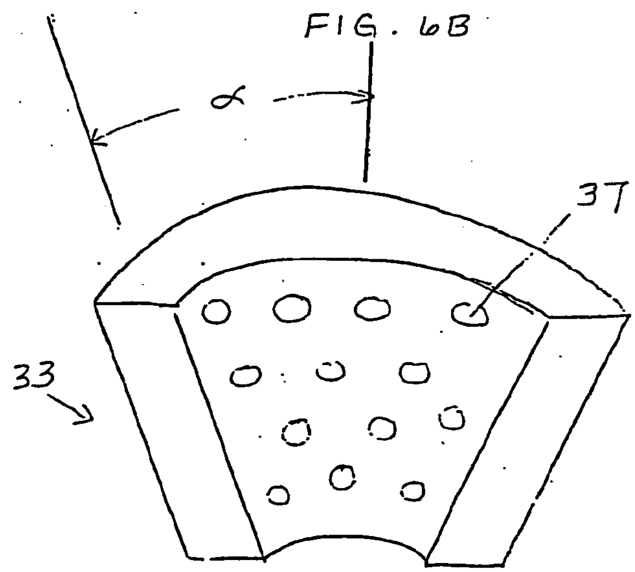


FIG. 7B

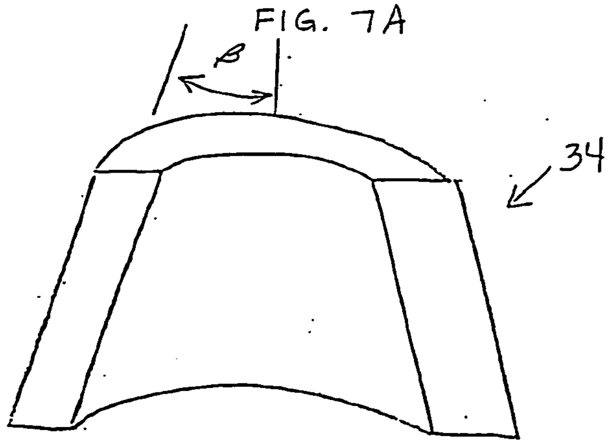


FIG. 8A

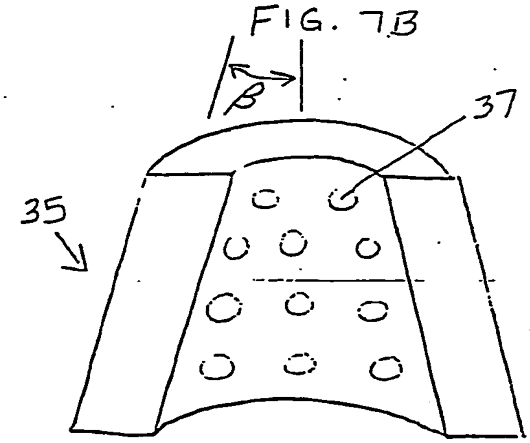


FIG. 8B

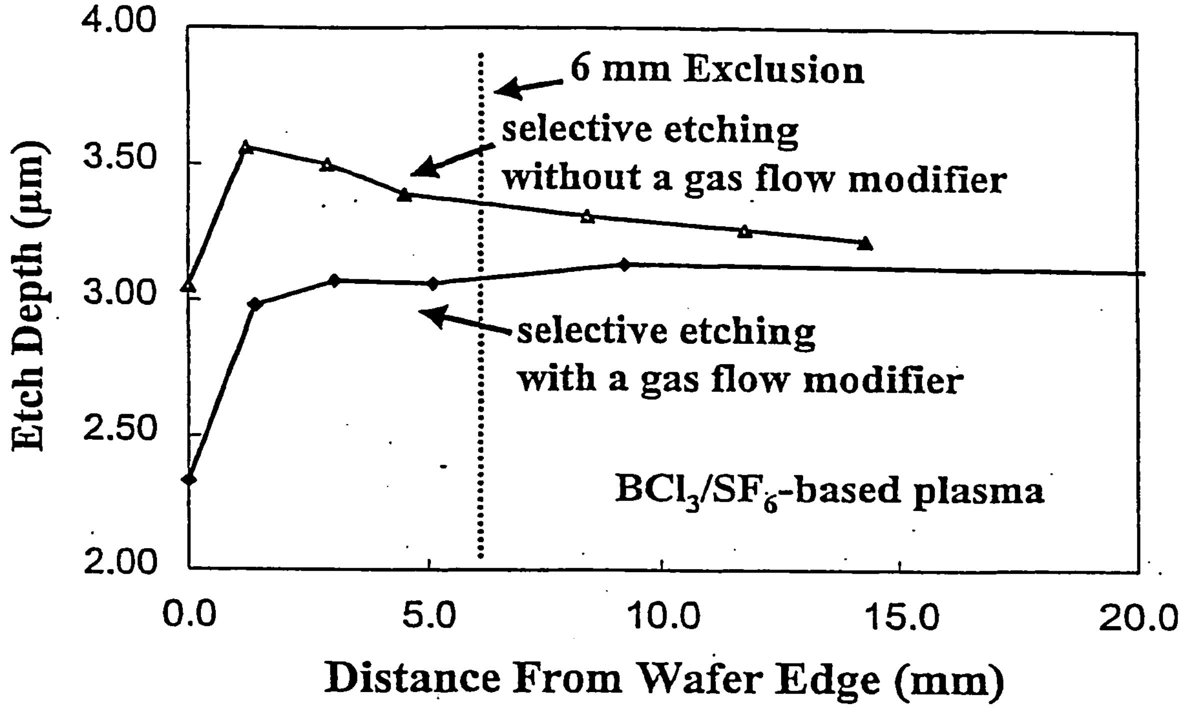


Figure 9. Radial distribution of etch depth of GaAs after selective plasma etching

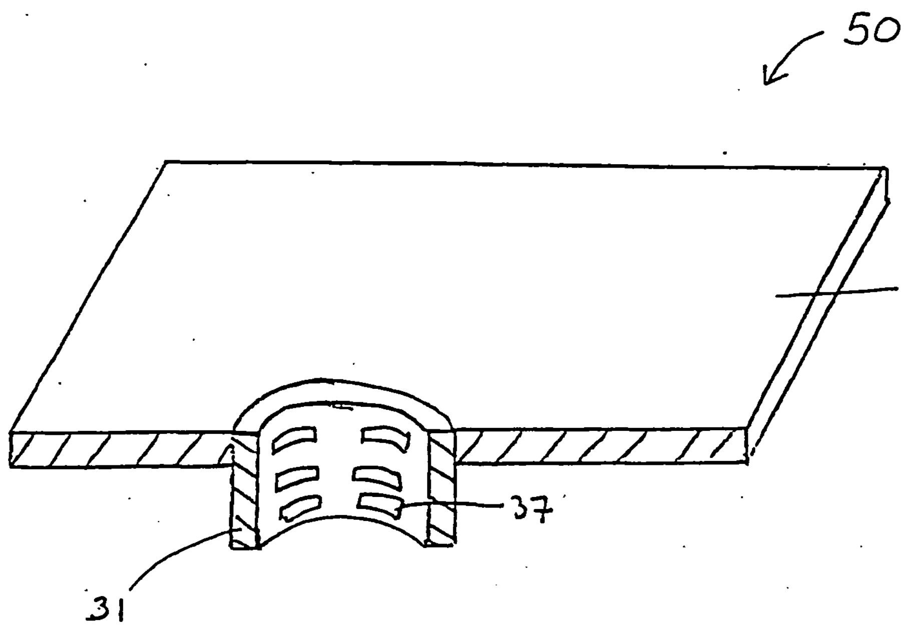


FIG. 10

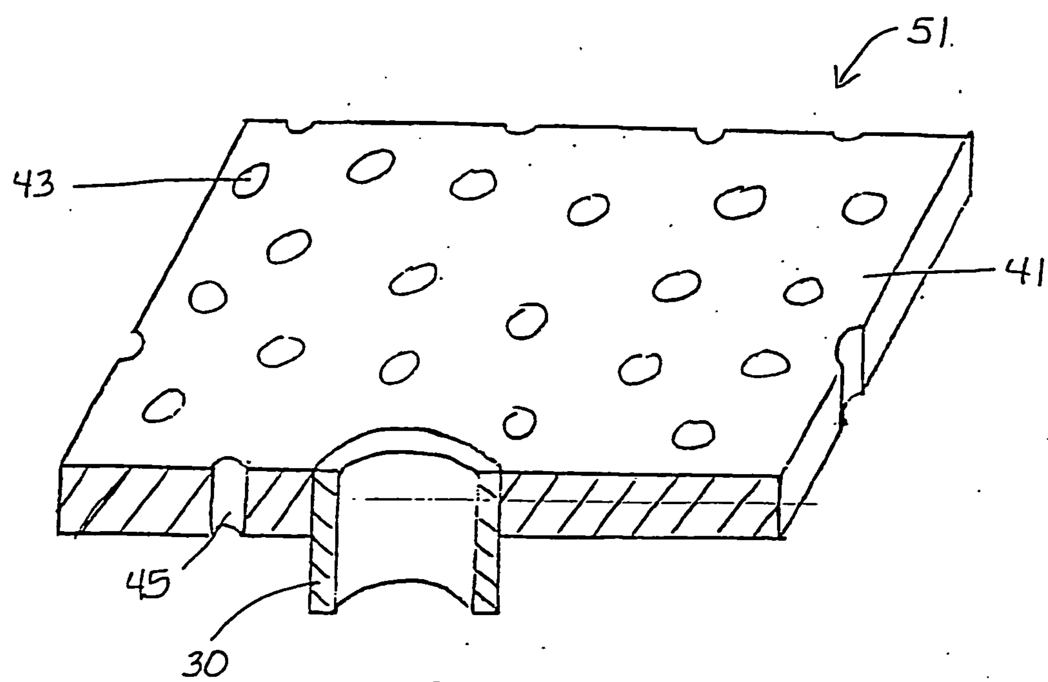


FIG. 11

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/41421

A. CLASSIFICATION OF SUBJECT MATTER

IPC(7) :H01L 31/06, 31/078
US CL : 438/710, 156/345
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 438/710, 156/345

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EAST

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 6,025,252 A (SHINDO et al.) 15 February 2000, column 85, lines 38-59.	1-27
A	US 5,705,042 A (LEIPHART et al.) 06 January 1998, column 3, lines 19-32.	1-27
A	US 5,985,102 A (LEIPHART) 16 November 1999 , col. 7, lines 17-40.	1-27

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:	"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"A" document defining the general state of the art which is not considered to be of particular relevance	"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"E" earlier document published on or after the international filing date	"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)	"&" document member of the same patent family
"O" document referring to an oral disclosure, use, exhibition or other means	
"P" document published prior to the international filing date but later than the priority date claimed	

Date of the actual completion of the international search 24 OCTOBER 2001	Date of mailing of the international search report 05 DEC 2001
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703) 305-3230	Authorized officer CHARLOTTE BROWN DEBORAH THOMAS PARALEGAL SPECIALIST Telephone No. (703) 308-0661